Plans and Concepts for a new generation of RTGs for Planetary Science Missions

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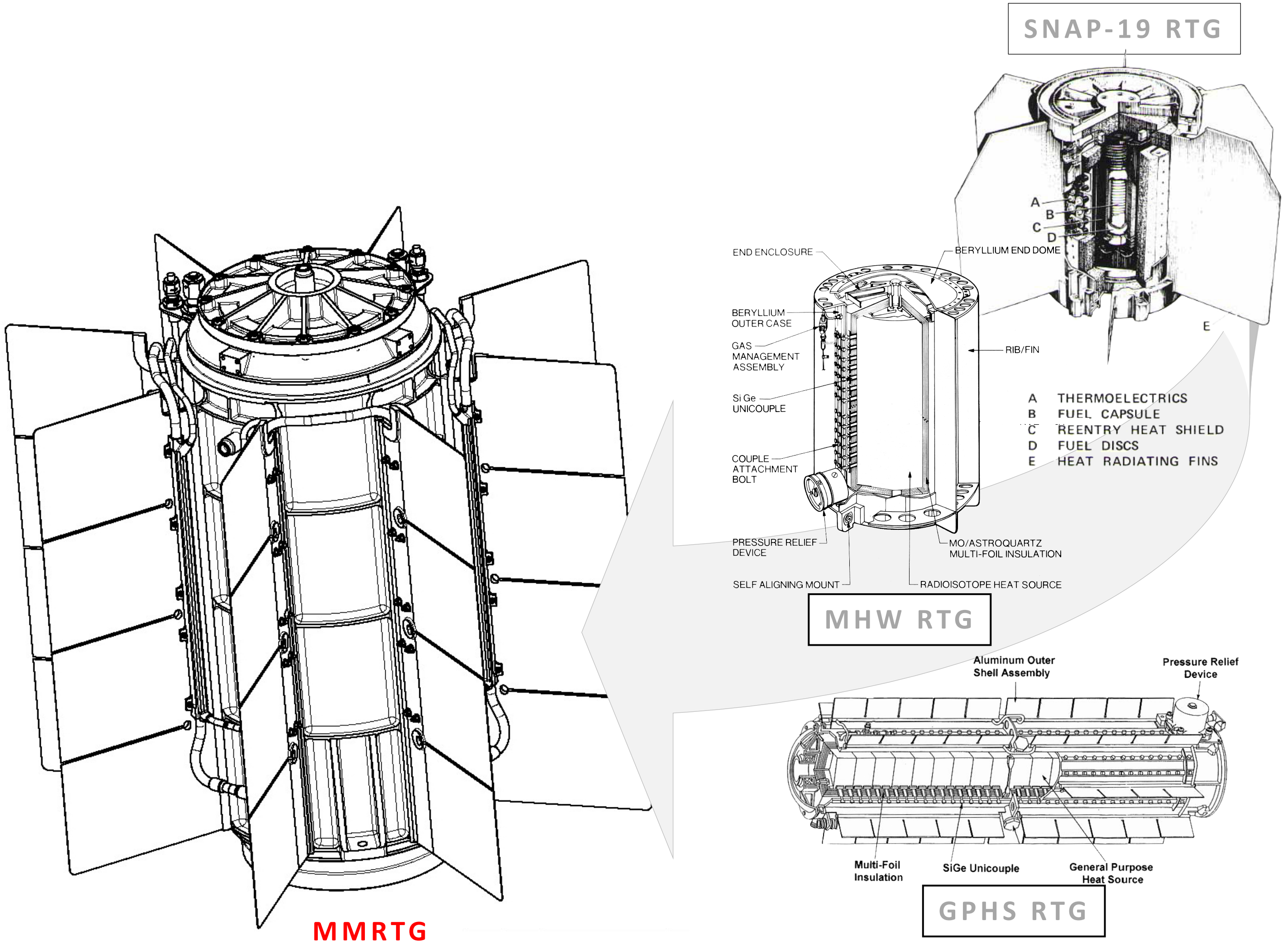
RTGs – Some background

- The DOE has produced a variety of RTGs that have been flown by NASA over the last 5 decades.
- RTGs convert heat produced from the decay of plutonium into quiet DC power.
- Only the MMRTG can be procured today.
- No moving parts
- An MMRTG weighs approximately 45 kg and produces 110W at launch.



NASA has flown 6 types of RTGs

Type	First Flight	Year	Mission	Thermoelectric Technology	Available Today?	Other significant features		
SNAP-19B3	NIMBUS III	1969	Meteorological	PbTe	No	Works in atmospheres	Non-modular	
SNAP-27	Apollo 12	1969	Lunar	PbTe	No	Works in atmospheres	Non-modular	
SNAP-19	Pioneer 10	1972	Planetary	PbTe/TAGS	No	Works in atmospheres	Non-modular	
MHW-RTG	LES-8	1976	Communications	SiGe	No	Vacuum-only	Non-modular	
GPHS-RTG	Galileo	1989	Jupiter orbiter	SiGe	No	Vacuum-only	Non-modular	
MMRTG	Curiosity	2011	Mars rover	PbTe/TAGS	Yes	Works in atmospheres	Non-modular	

GPHS-RTG – General-Purpose Heat Source RTG
MHW-RTG – Multi-hundred Watt
MMRTG – Multi-Mission RTG
RTG – Radioisotope Thermoelectric Generator
SNAP – Systems for Nuclear Auxiliary Power

An eMMRTG Concept

The eMMRTG concept is born

- MSL landed on August 5, 2012 powered by an MMRTG producing ~114W
- JPL presented RTG technologies for an enhancement to the MMRTG to the Director of NASA's Planetary Science Division a couple of days later
- Systems engineering of the enhanced MMRTG (eMMRTG) and its associated technologies were funded in the subsequent year.
- This effort is now in its 5th year

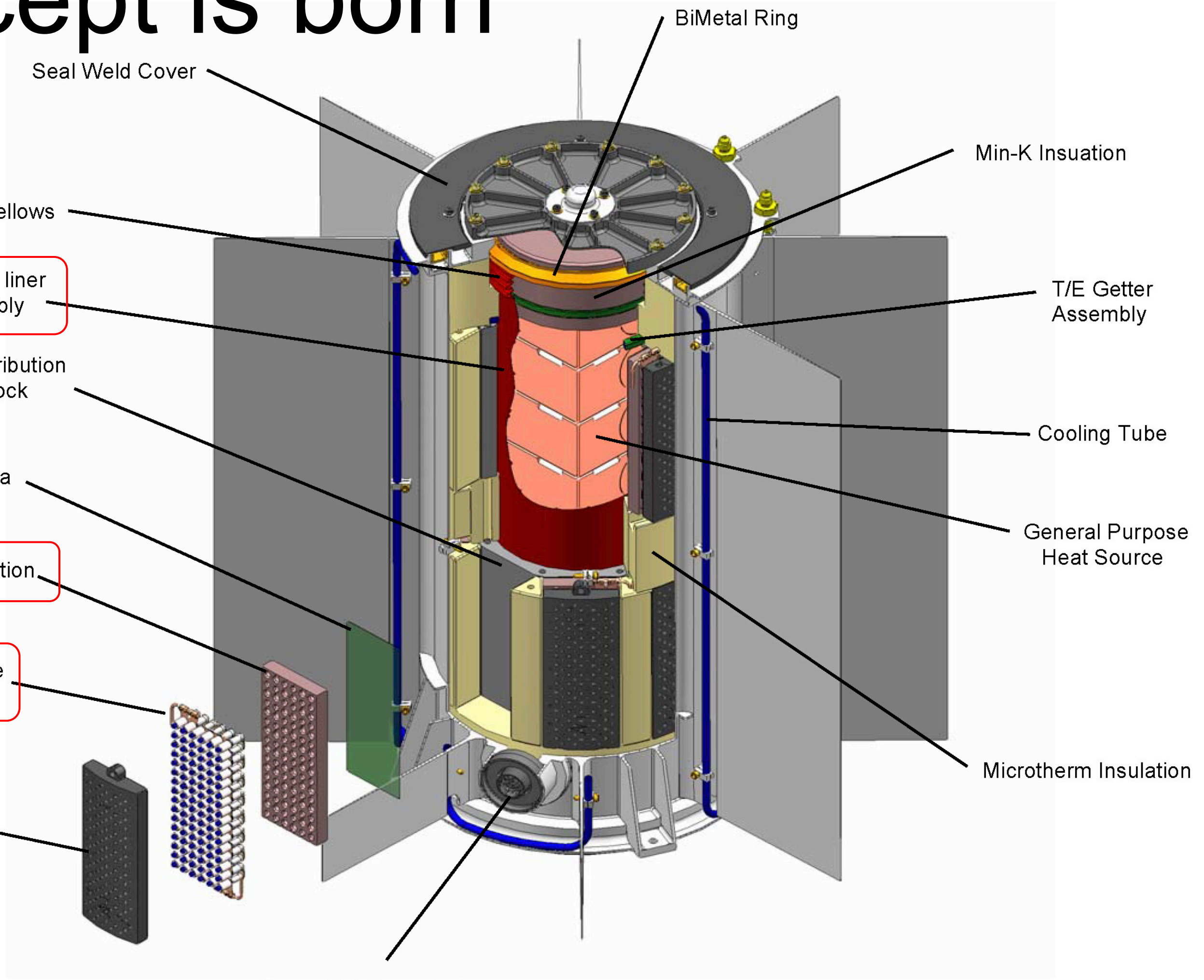
The eMMRTG concept is born

Known enhancements

Engineering: emissivity change to liner, substitute insolation

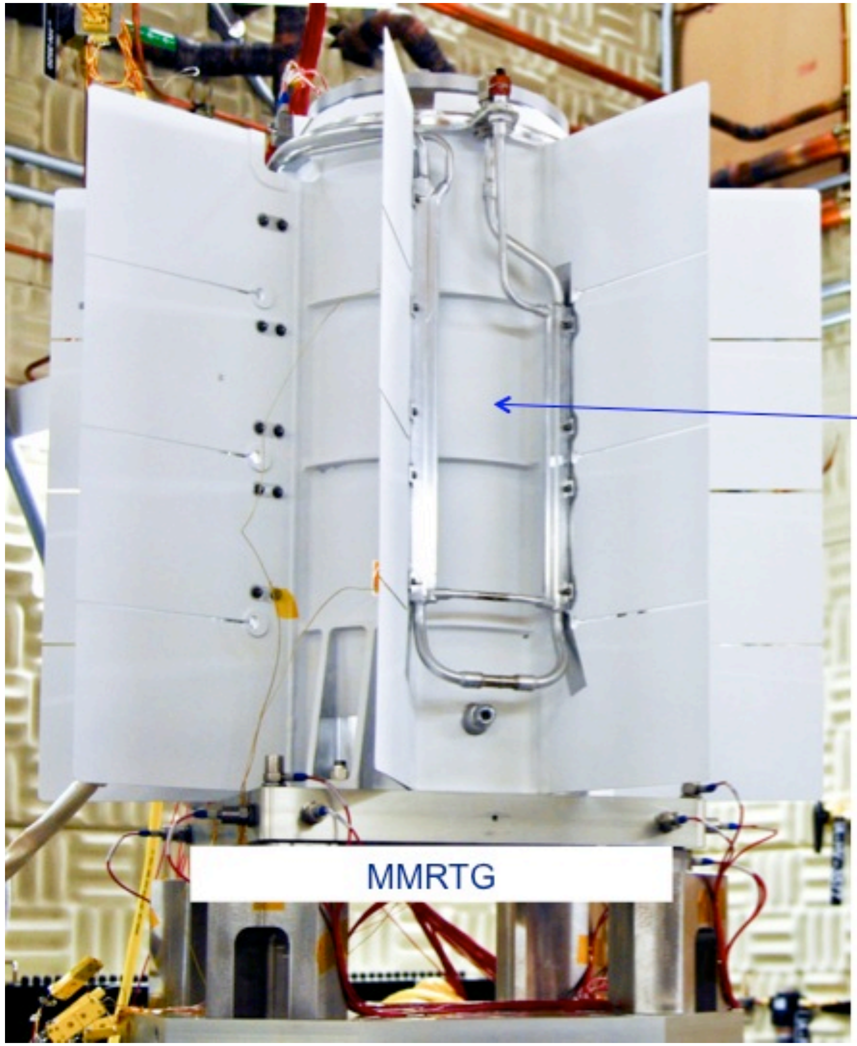
Changes needed to MMRTG

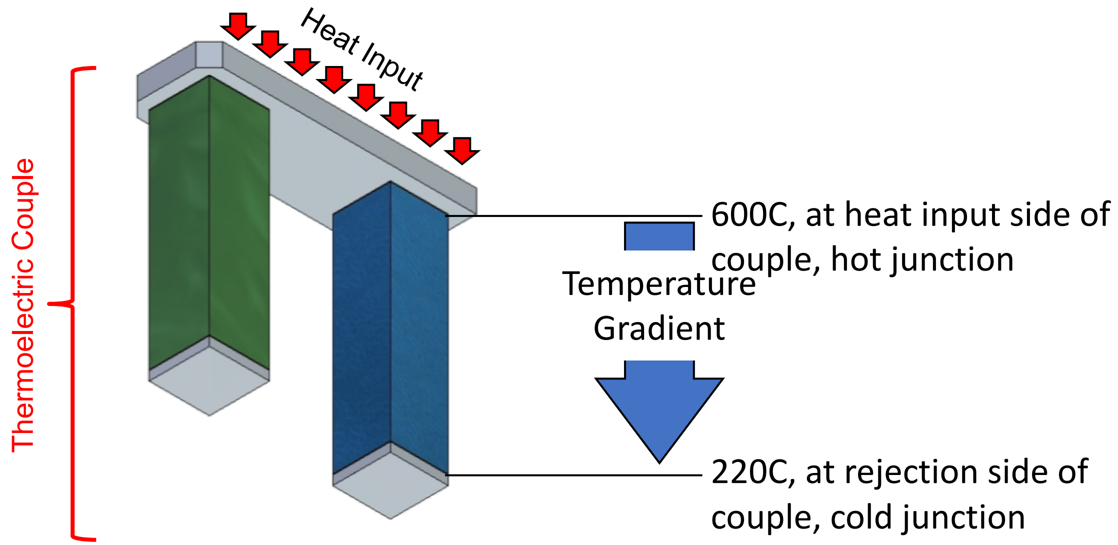
New Technology: Substitute SKD TECs



Retrofitting the MMRTG with new Skutterudite thermoelectric couples is low risk
- Skutterudite couples fit within the space available
- Volume, mass, and external interfaces remain unchanged
- Multi-mission capability preserved

Skutterudite thermoelectric couples





A Next-Generation RTG Concept

The Next-Generation RTG Study

- NASA funded the study in 2016 and was motivated by the need for more powerful RTGs than presently available
- Serve NASA for 2-3 decades to come starting in ~2030
- To address the needs of future Decadal Survey missions
  - An RTG that would be useful across the Solar System
  - An RTG that maximizes the types of missions: flyby, orbit, land, rove, boats, submersibles, balloons
  - An RTG that has reasonable development risks and timeline

The Next-Generation RTG Study Team

- Drew on the talent and experience:
  - at three NASA centers:
    - Goddard Space Flight Center,
    - Glenn Research Center,
    - and the Jet Propulsion Laboratory/California Institute of Technology,
  - as well as the US Department of Energy,
  - the John Hopkins University’s Applied Physics Laboratory,
  - and the University of Dayton Research Institute.

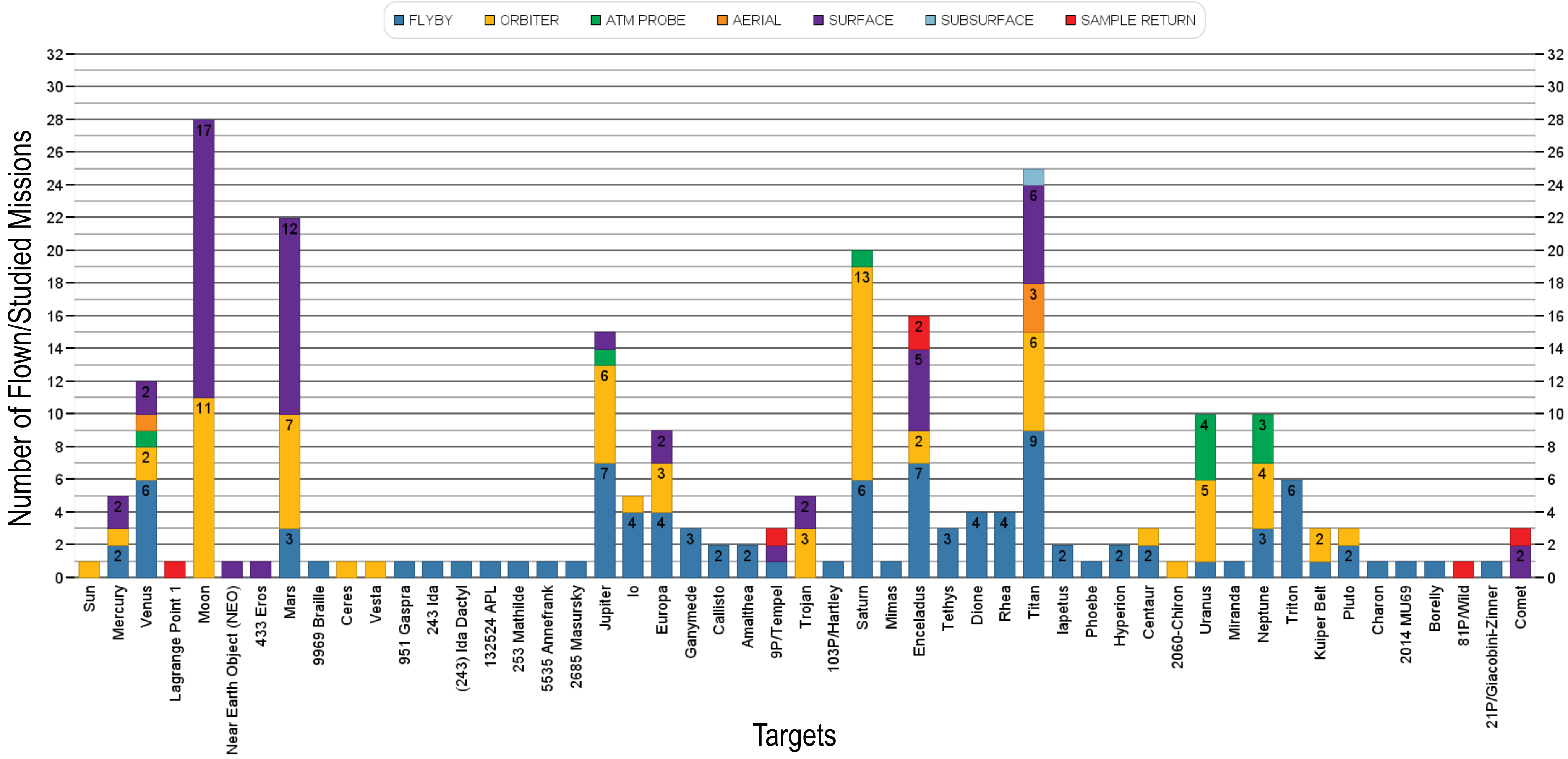
Next-Generation RTGs – *Mission Analyses*

- Review and Analyze prioritized missions recommended in Planetary Science Decadal Surveys
  - These are roadmaps used by NASA
- Review and Analyze other mission studies performed within the Agency and without.
- Include destinations within the Solar System not yet studied

An RTG that would be useful across the Solar System

Next-Generation RTGs – *Mission Analyses*

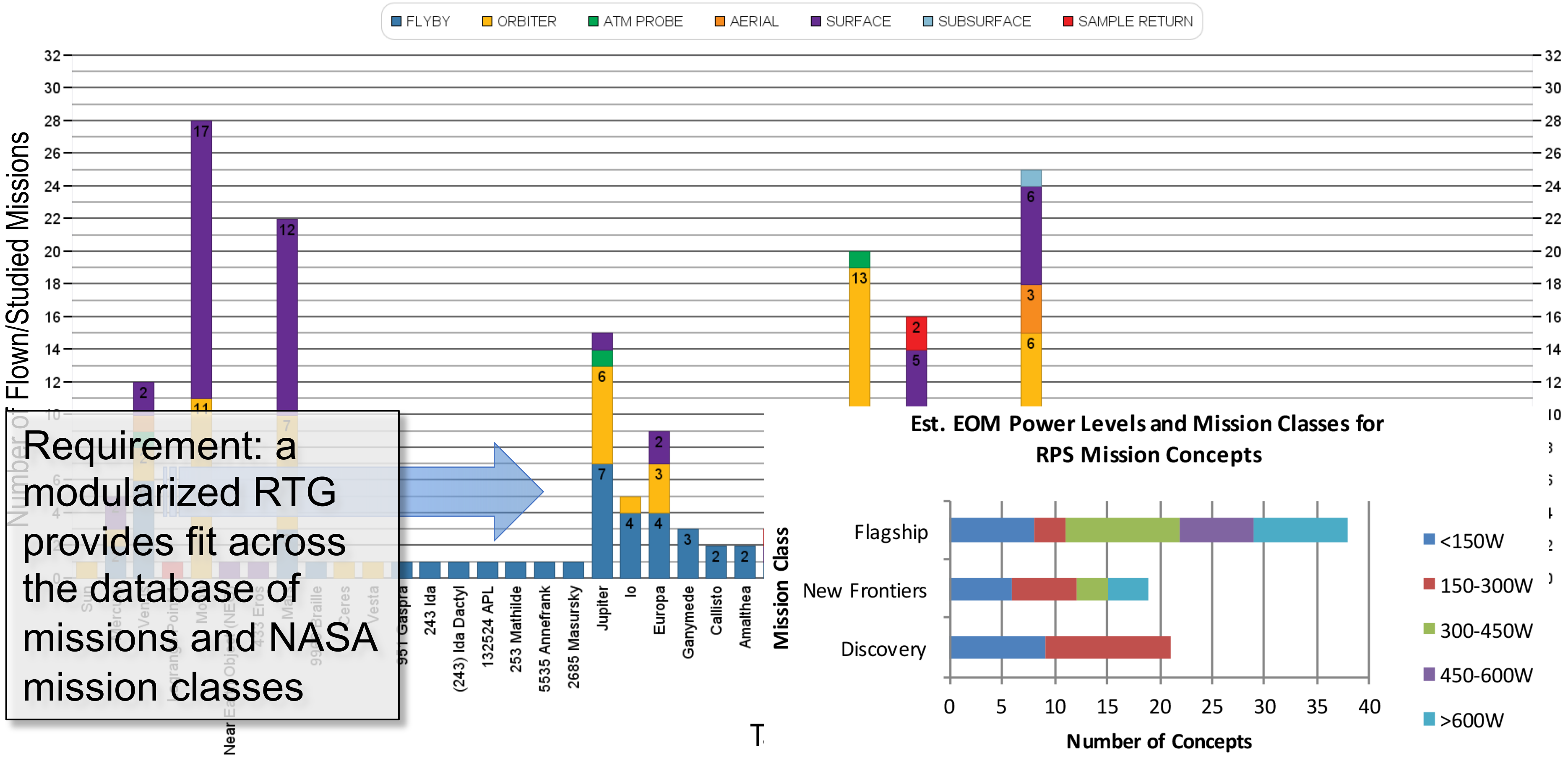
249 Mission Studies in database



Pre-Decisional Information – For Planning Purposes Only

Next-Generation RTGs – *Mission Analyses (MA)*

Example of a requirement derived from Mission Analyses

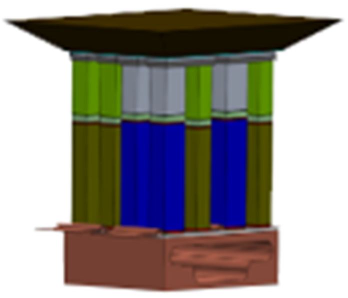


Next-Generation RTGs – *Segmented Couple Configurations*

Technology Scorecard

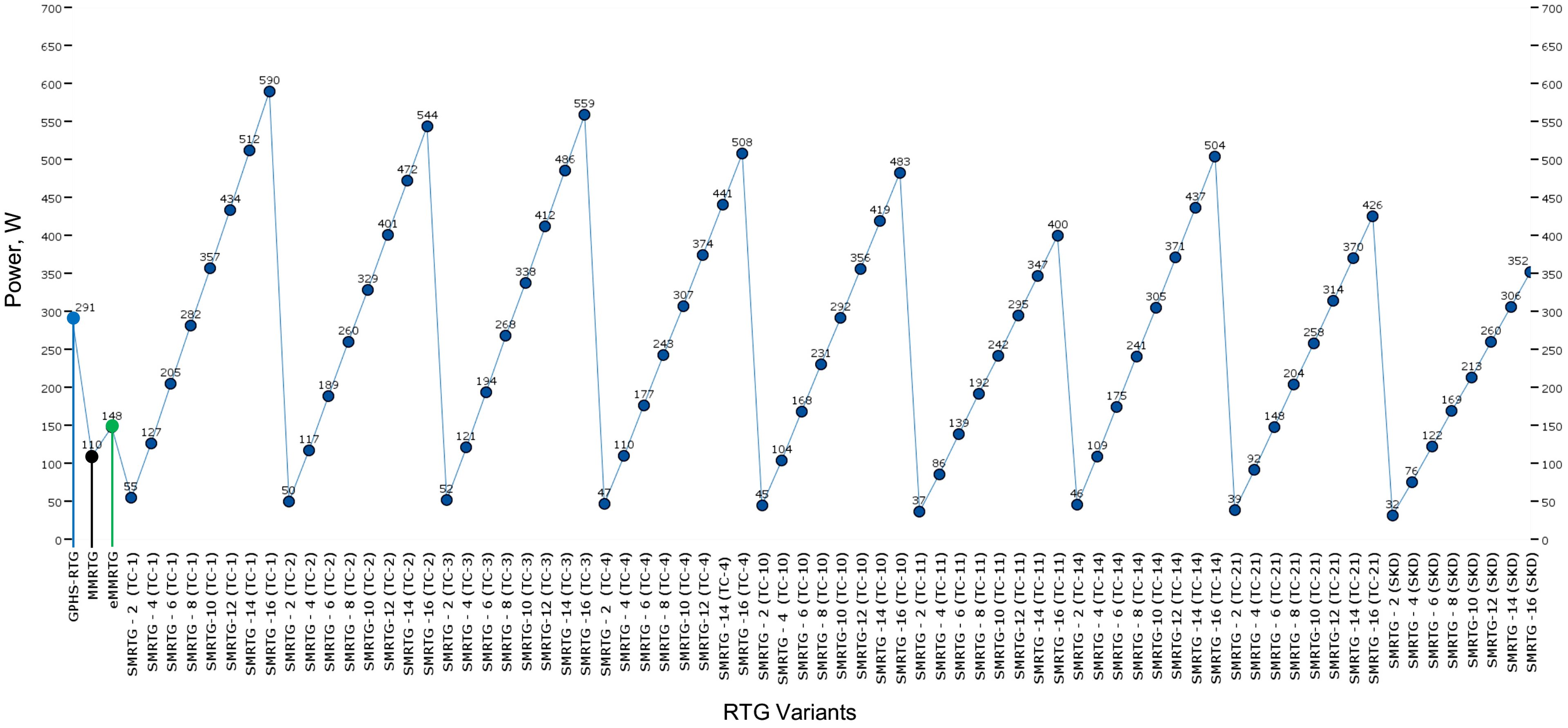
Configuration	Segments per Leg	Segment TRL (L/M/H)		TRL	Efficiency			TE Cavity Atmosphere rating	Sublimation rating		Segmentation Ratings				Hot Side Metallization Rating		Score	
		n-type	p-type	Config.	1275K T_{hj} 450K T_{cj}	875K T_{hj} 450K T_{cj}	Efficiency 875K T_{hj} 350K T_{cj}		n-leg	p-leg	CTE mismatch	Complexity	n-leg Top/Mid Segment Interface	p-leg Top/Mid Segment Interface	n-leg	p-leg	Weighted	Unweighted
1	3	9/2/2	9/2.5/3.5	1	16.5			4	4	3	4	2	3	4	4	3	273	49
2	3	9/2/3.5	9/2.5/3.5	1	15.3			4	4	3	4	2	3	4	4	3	263	47
3	3	9/4/2	9/4/3.5	2	15.8			4	4	3	1	2	2	2	4	3	254	43
4	3	9/4/3.5	9/4/3.5	3	14.3			4	4	3	1	2	2	2	4	3	256	42
5	3	9/3/2	9/3/3.5	0	16.1			4	1	3	3	2	1	1	4	3	223	38
6	3	9/3/2	9/3/3.5	0	14.3			4	4	3	1	2	3	3	4	3	220	41
7	3	9/9/2	9/9/3.5	1	15.6			2	3	3	3	2	3	3	4	3	243	43
8	3	9/9/2	9/9/3.5	1	15.6			2	3	3	3	2	3	3	4	3	243	43
9	2	3/2.5	3/2.5	0	11.8			4	1	4	1	3	3	3	1	1	175	33
10	1	2	3.5	2	13.8			4	4	3	4	3	4	4	4	3	271	49
11	1	3.5	3.5	3.5	11.3			4	4	3	4	4	4	4	4	3	275	49
12	1	2.5	2.5	2.5	9.8			4	4	4	4	4	4	4	1	1	233	42
14	2	9/2	9/3.5	1	14.0			4	4	3	4	3	3	3	4	3	253	46
17	3	9/3/3.5	9/3/3.5	0	14.5			4	1	4	3	2	1	1	4	3	214	38
18	3	9/3/3.5	9/3/3.5	0	13.1			4	4	3	1	2	3	3	4	3	211	40
19	3	9/9/3.5	9/9/3.5	1	14.0			2	3	3	3	2	3	3	4	3	230	41
20	3	9/9/3.5	9/9/3.5	1	14.3			2	3	3	3	2	3	3	4	3	232	41
21	2	9/3.5	9/3.5	2	12.0			4	4	3	4	3	3	3	4	3	251	45
		Weighting		14	8	8	8	5	4	4	6	3	3	3	4	4		
				<1					High: $\geq 10^{-4}$ g/cm²/hr		≥30%	Significant Development Effort Required (>3 Years)						
				1≤x<2	<12%	<12%	<12%	Ar only	Medium: $10^{-4}>x>10^{-5}$ g/cm²/hr		20≤x<30 %	Major Development Effort Required (2-3 Years)					<230	<42
				2≤x<3	12≤x<14 %	12≤x<14 %	12≤x<14 %	Vacuum/ Ar	Low: $10^{-5}>x>10^{-6}$ g/cm²/hr		10≤x<20 %	Minor Development Effort Required (1 -2 Years)					230≤x<250	42≤x<47
				≥3	≥14%	≥14%	≥14%		Very Low: $\leq 10^{-6}$ g/cm²/hr		<10%	Minimal Development Required (≤ 1 year)					≥250	≥47

Single couple device



Multicouple device for supporting modular RTG capability

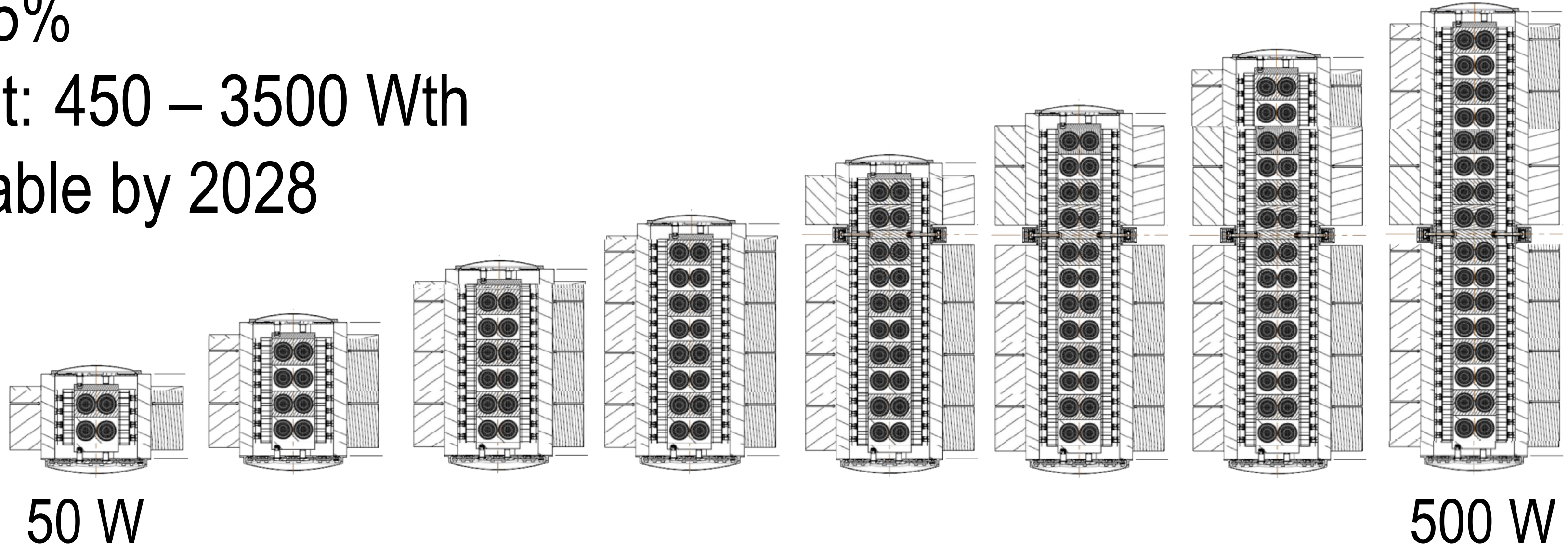
Next-Generation RTGs for NASA – *Power*



Next-Generation RTGs – *Concepts*

- Conceptual Next-Generation RTGs *

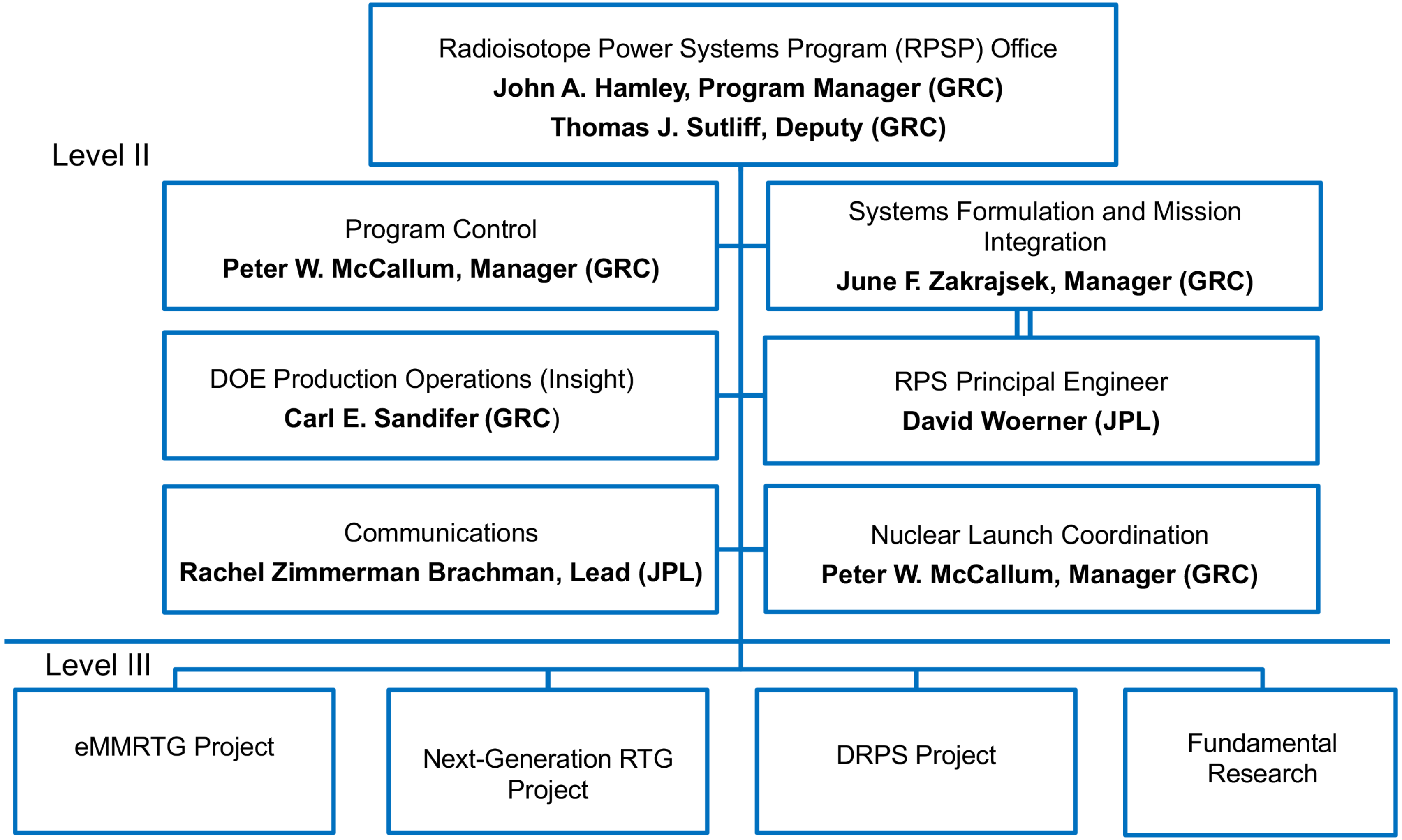
Modular: 50 – 500 W (Beginning Of Life)
20 – 60 kg
Efficient: 10-15%
Copious waste heat: 450 – 3500 Wth
Within reach, available by 2028



* Artist concepts from: Woerner, et al, *Next-Generation Radioisotope Thermoelectric Generator Study Final Report* June, 2018, JPL-internal Document: JPL D-99657

The Program and Projects

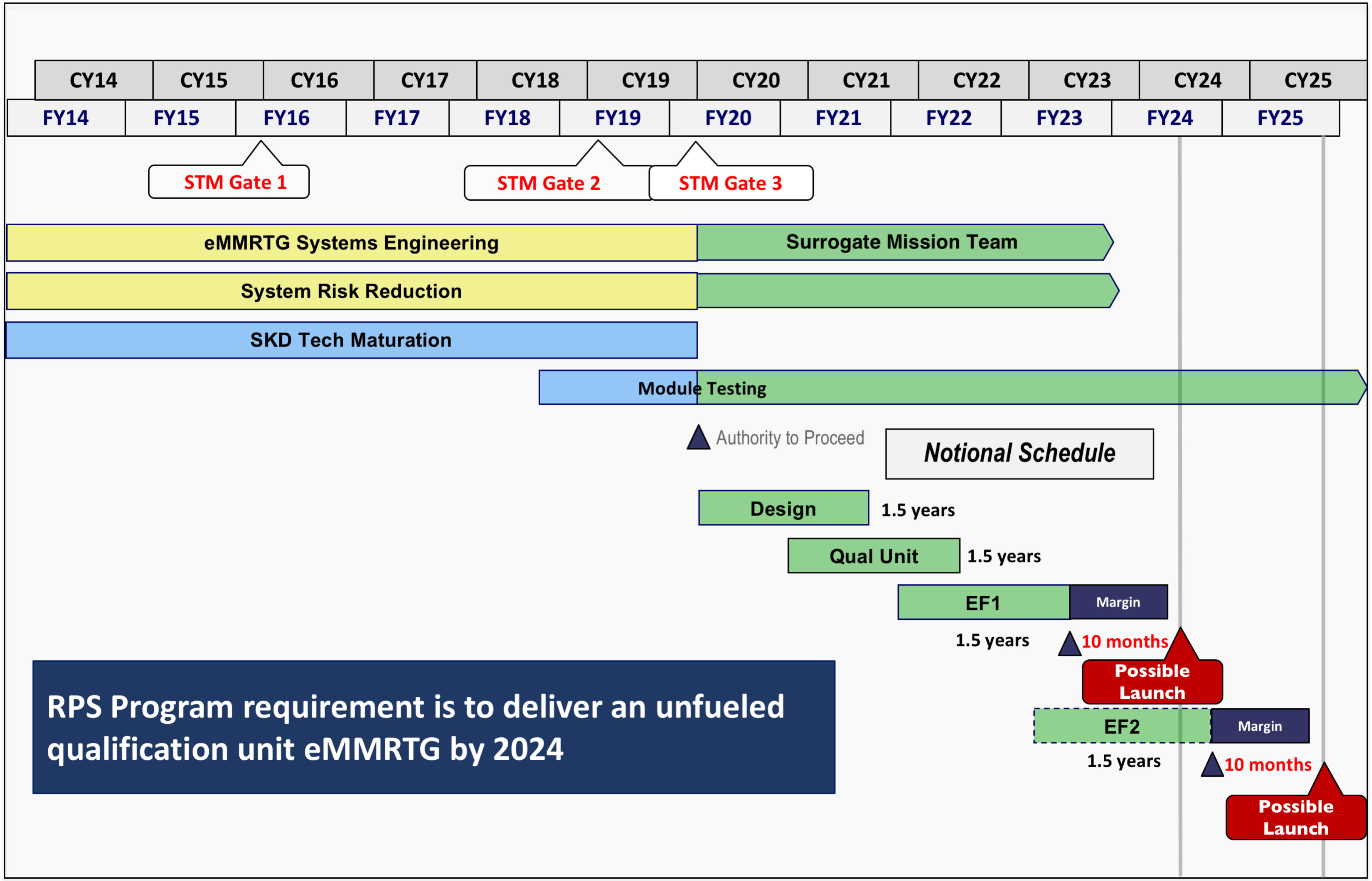
NASA's RPS Program and Projects



RPS – Radioisotope Power Systems

The eMMRTG Project

eMMRTG Notional Schedule



The NG-RTG Project

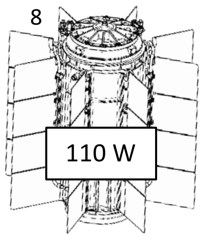
NG-RTG Project Background

- The Next-Generation RTG Project was created in 2018 to deliver an unfueled qualification unit by 2028
- The Project Office has selected systems engineers and is funding further technology development at JPL.
- The Project issued a Sources Sought Notice to industry and held a Technical Interchange Meeting with potential subcontractors,
- The Project will issue an RFP for NG-RTG System Concepts tasks in 2019.

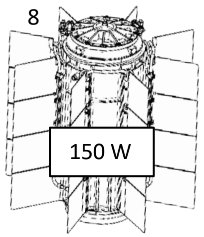
Comparisons

A few RTGs side-by-side

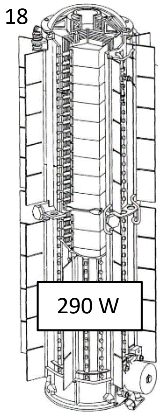
MMRTG,
Curiosity,
M2020,
Dragonfly



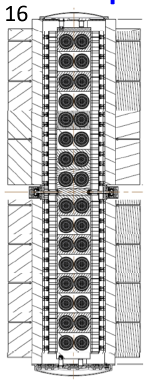
eMMRTG Concept



GPHS RTG,
Cassini,
Galileo,
Ulysses



Next-Gen RTG Concept



Power, launch, W	110	140	290	400-500
Efficiency, BOL	5.5%	7.5%	6.4%	10-12.5%
Power, end of life, W	55	91	213	308-385
Degradation rate, av	4.8%	2.5%	1.9%	1.9%
# GPHSs	8	8	18	16
Length, m	0.69	0.69	1.14	1.04
Mass, kg	45	44	57	62

Next-Gen RTG would nearly double the power over equivalent RTG.
eMMRTG and NG-RTG would satisfy PSD's needs for the next 2-3 decades.

NASA is now well on the way to developing a new generation of RTGs for Planetary Science Missions

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